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PARTIAL DISCHARGE TESTING OF HIGH VOLTAGE WIRING HARNESS FOR AIRBORNE DISPLAYS

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The pilots of advanced tactical airplanes must evaluate increasingly more information. Innovations such as the "heads-up" display were designed to decrease the visual workload. More flexible helmet-mounted CRTs are now being developed, presenting new design challenges. For example, high voltage leads for helmet-mounted displays must incorporate a quick release, load-break mechanism into the wiring harness to accommodate pilot ejection. The potential presence of flammable vapors resulted in an arc-suppressing, quick-disconnect, connector design which opens the high voltage via hermetically sealed contacts. The sealed contacts contain any arcing and break the circuit before the connector separates. The prototype harness routes two 13.5 kilovolt rated direct current leads along with other wiring via the quick-disconnect connector. The high voltage and compact design motivate concerns about partial discharge degradation of the insulation, particularly at sub-atmospheric pressures. The harness has been tested for partial discharges at simulated altitudes up to 70,000 feet in the Aerospace Power Division's High Power Laboratory.

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1.0 INTRODUCTION

The pilots of advanced tactical airplanes must evaluate increasingly more information. Innovations such as the "heads-up" display were designed to decrease the visual workload. More flexible helmet-mounted CRTs are now being developed, presenting new design challenges. For example, high voltage leads for helmet-mounted displays must incorporate a quick release, load-break mechanism to accommodate pilot ejection. The potential presence of flammable vapors resulted in an arc-suppressing, quick-disconnect, connector design which opens the high voltage via hermetically sealed contacts. The sealed contacts contain any arcing and break the circuit before the connector separates.

A prototype harness for a helmet mounted display (HMD) and tracker has been designed jointly by the University of Dayton Research Institute and Reynolds Inc. under the sponsorship of Armstrong Laboratory. The harness routes two 13.5 kilovolt rated direct current leads along with other wiring via the quick-disconnect connector. The high voltage and compact design motivate concerns about partial discharge degradation of the insulation, particularly at sub-atmospheric pressures. The harness has been tested at simulated altitudes up to 70,000 feet, at operating voltage.

While several visual display methods have been tried in HMDs, currently only cathode ray tubes (CRTs) with their required high voltages are bright enough to provide satisfactory daytime performance. Unfortunately, high voltage leads and connectors are potential sources of partial discharge. Partial discharge (PD) in the high voltage leads and/or connector section can induce electrical noise on adjacent video lines, as well as shorten insulation lifetimes. In this application, the high voltage leads are unshielded, high quality, fluorinated ethylene-propylene copolymer (FEP) insulated wires.

The custom, high voltage interruption mechanism section is incorporated in a grounded quick-disconnect connector (QDC) for spark free, emergency pilot egress[1]. The QDC has a maximum cross section of 2.85 x 1.48 inches and is 4.8

inches long. The QDC construction is shown in Figure 1, with the QDC just starting to de-mate. This configuration ensures that when de-mating, the internal, sealed SF_6-filled circuit breaker interface opens before the pilot/aircraft interface and when mating, closes after the pilot/aircraft interface. Thus, the pilot/aircraft interface can never be "hot" except when the QDC is fully mated.

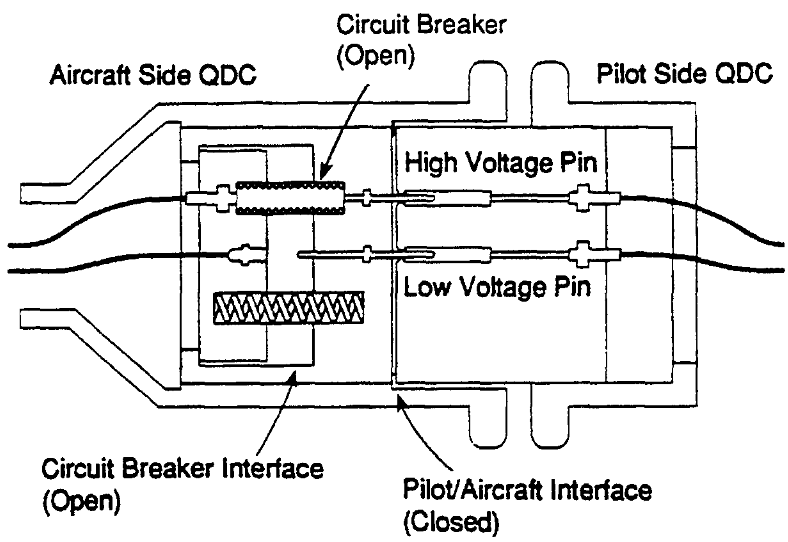

Figure 1. Quick-Disconnect Connector

2.0 PARTIAL DISCHARGE TEST CONDITIONS

For the same power level, the higher the CRT operating voltage, the longer the tube life. A 13.5 kilovolt CRT was targeted as the desired configuration. As "fall back" designs, 12.5 and 8 kilovolt CRTs were considered as well. Hence, the harness assembly was tested at three voltages: 13.5, 12.5 and 8 kilovolts.

To simulate representative atmospheric conditions, three test pressures were utilized. The values of 750 torr (approx. ground level) and 34 torr (simulated 70,000 feet) were used to cover the extrema. A value of 280 torr (minimum normal cabin pressure) was also used.

The test circuit employed is similar to Circuit No. 1 from ASTM D 1868-8 (Fig. 2). The harness was tested both with the connector open and closed, in order to

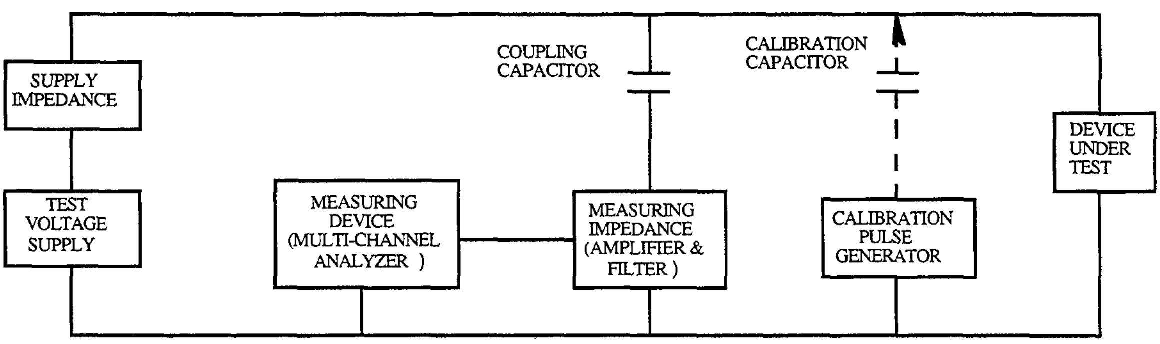

Figure 2. Test Circuit

provide information about the relative levels of partial discharge activity in the two halves of the harness. The two high voltage leads were tested singly and together to test for manufacturing consistency. Partial discharges between 4 and 2048 picoCoulombs (pC) were recorded with a multi-channel analyzer with 1024 channels. Partial discharges above 2048 pC were logged with a single channel analyzer that did not discriminate pulse height.

Figure 3 shows the test schematic. All test runs were three minutes long. "Ramping up" the test voltage from zero took approximately 15 seconds. To stabilize the instrumentation, a dwell time of one minute was used after the test voltage level was attained. Then, the multichannel analyzer was turned on for the three minute test run. Each test combination of voltage, pressure, connector position (open/closed), and lead connection was run ten times, to provide a data set for statistical comparisons.

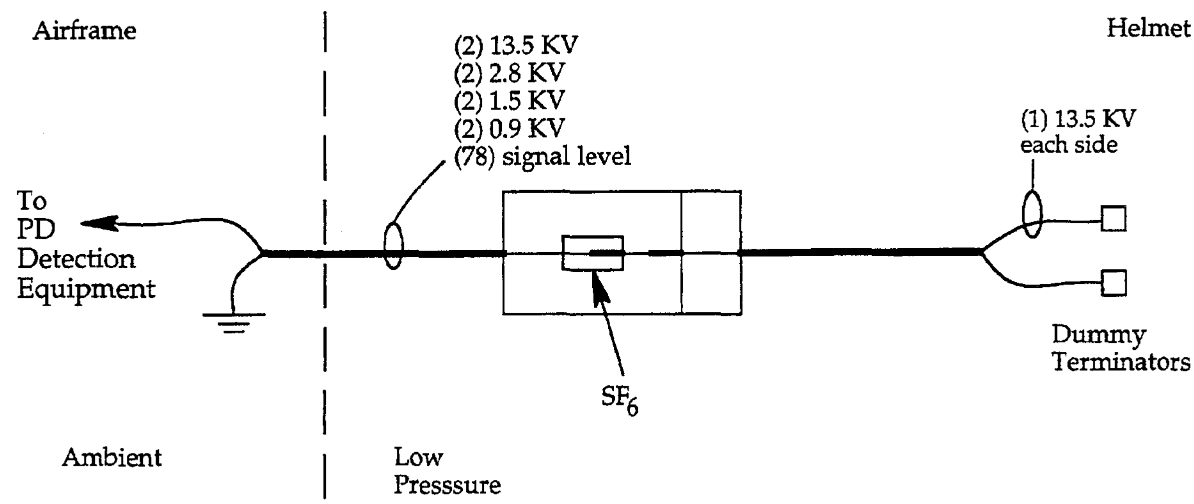

Figure 3. Harness Schematic

3.0 RESULTS

A histogram can illustrate the result of a test run. Figure 4 shows an example for a test run at 13.5 kV and one atmosphere. The connector was in the closed configuration and both leads were energized.

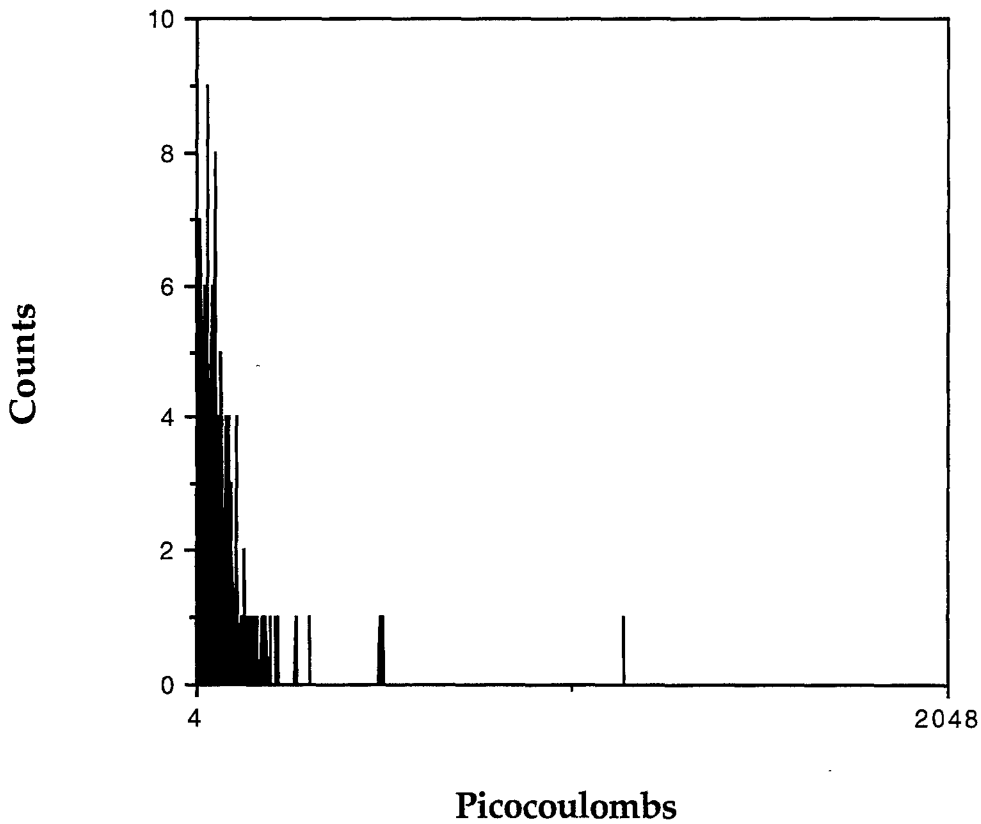

Figure 4. Histogram Showing Counts vs. Picocoulombs

For overall results the ten runs for each experimental condition are averaged. As expected, partial discharge activity increases (Fig. 5) with increasing test voltage. Each vertical stack in the figure represents ten tests of the harness with the connector open. The test to test variation under identical conditions can be seen to be relatively high. This is not unusual for partial discharge tests with applied dc voltage. (For ac testing, such variations are typically much less.)

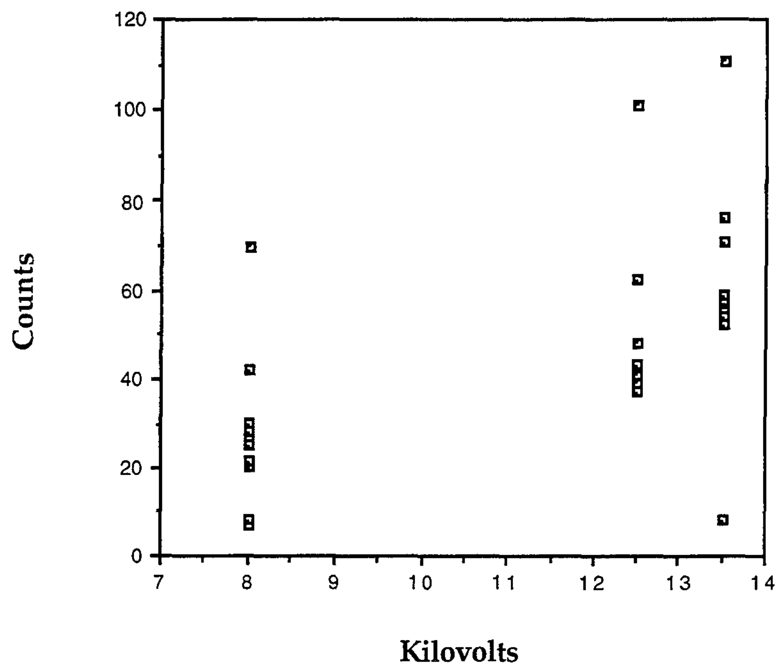

Figure 5. Voltage vs. Counts at Room Pressure

Figure 6 shows that at simulated ground level and minimum cockpit pressurization, counts are low compared to the simulated 70,000 feet. Each column represents ten tests of the closed harness. The lack of variation within the test groupings at ground level and minimum cabin pressure is encouraging. Since the harness will only see 34 torr under rare emergency conditions, the increase in partial discharge activity at this low pressure is a minimal concern.

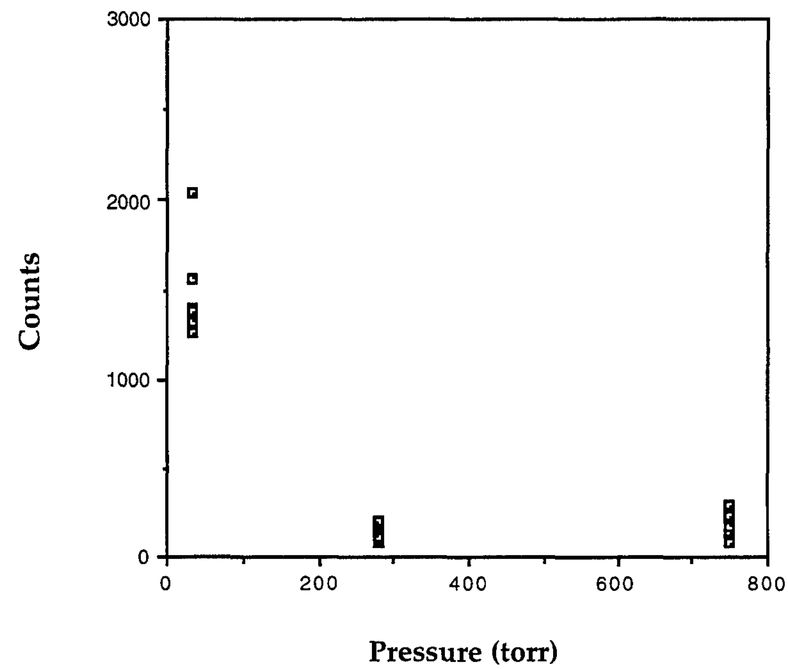

Figure 6. Pressure vs. Counts at 13.5 kV

Corona Inception Voltages (CIV) were also recorded at 34 and 750 torr. The CIV criterion was the presence of multiple counts above 4 pC during a three minute test period. The CIV threshold was easily discernable and repeatable. Using the entire harness, complete with mated connector, resulted in a CIV of 3.4 kilovolts at 750 torr and a CIV of 1.3 kilovolts at 34 torr. These CIV values are all well below the proposed operational ratings of 8, 12.5 or 13.5 kilovolts.

For the following tables, "Counts" and "Counts Over Range" are average values taken over 10 independent runs. The range for "Counts" is between 4 pC and 2048 pC . "Counts Over Range" are amplitudes over 2048 pC. Table 1 shows that only at the minimum pressure of 34 torr does one high voltage lead perform significantly differently from the other lead when comparing average counts. Table 2 gives the values for a comparison of connector position with both leads energized.

Table 1. Comparison of Wires: Harness A at 13.5 kV

Wire(s)	Pressure	Position	Counts	Counts Over Range
1	1 atm.	Open	29	0.1
1	1 atm.	Closed	63	1.0
1	34 Torr	Open	15	1.5
1	34 Torr	Closed	570	67.6
2	1 atm.	Open	33	0.3
2	1 atm.	Closed	48	0.8
2	34 Torr	Open	12	4.2
2	34 Torr	Closed	228	5.8

Table 2. Comparison of Connector Positions for Both Wires Energized at 13.5 kV

Pressure	Position	Counts	Counts Over Range
1 atm.	Open	60	0.2
280 Torr	Open	38	1.9
34 Torr	Open	25	15.9
1 atm.	Closed	173	2.6
280 Torr	Closed	132	4.6
34 Torr	Closed	1434	51.9

For all three pressures, the closed position had more partial discharges. A "t test" was performed for the two connector positions at each pressure. Calculations show that the connector position is important, i.e. using the standard 5% significance criterion, the differences between average counts are significant. In practice, this means that when the entire harness was energized, partial discharge activity was greatest. (It should be noted that this could be attributable to either the construction of the harness wiring or the dummy terminations.)

Two pilot half-harnesses were tested to see if any performance differences between half-harnesses existed. Table 3 shows the partial discharge performance of the half-harnesses A and B. Harness B performs much worse than harness A.

Table 3. Harness A & B at Room Pressure and 13.5 kV in Closed Position

Sample	Wire(s)	Counts	Counts Over Range
A	1, 2	173	2.6
A	1	63	1.0
A	2	48	0.8
B	1,2	1016	44
B	1	867	29
B	2	672	10.2

So far the only measure of performance discussed has been the number of partial discharge counts. Another performance metric is integrated charge. Integrated charge can be calculated by summing the multiplication of the number of pulses in each channel of the charge spectrum by the charge value. The average charge rate is simply the integrated charge divided by the run time. The equation can be written:

$$R_Q = \frac{\sum_{i}^{k} n_i Q_i}{t}$$

where R_Q is the charge rate, n is number of counts, Q is the charge/channel, i is the channel number, k is the total number of channels, and t is the run time in seconds. While R_Q has the same units as current, it should not be confused with average current. All discharges below 4 picocoulombs are neglected in these tests. The corona detection system used cannot discriminate actual pulse durations nor resolve simultaneous pulses from spatially different discharge sites. Hence, the amplitude of a count may actually be due to multiple sources.

Figure 7 shows integrated charge versus kilovolts for harness A at one atmosphere. The data can be seen to approximately follow an exponential curve fit. This is not considered a "best fit" since the number of data points is so limited. Rather it is suggested as an empirical trend, assuming that most of the discharges were in the wiring transition region between the end of the cable sheath and the CRT connections. As such discharges can be described by a Townsend-like avalanche growth process, it is possible that an exponential total charge versus energization voltage relationship might exist. However, the few data points seem to show that the trend may be steeper than the fit would indicate. This could be due to additional enhancement factors brought into play by the practical (non-Townsend) geometry of the harness. Many more tests would have to be run on multiple samples in order to conclusively relate integrated charge to applied voltage.

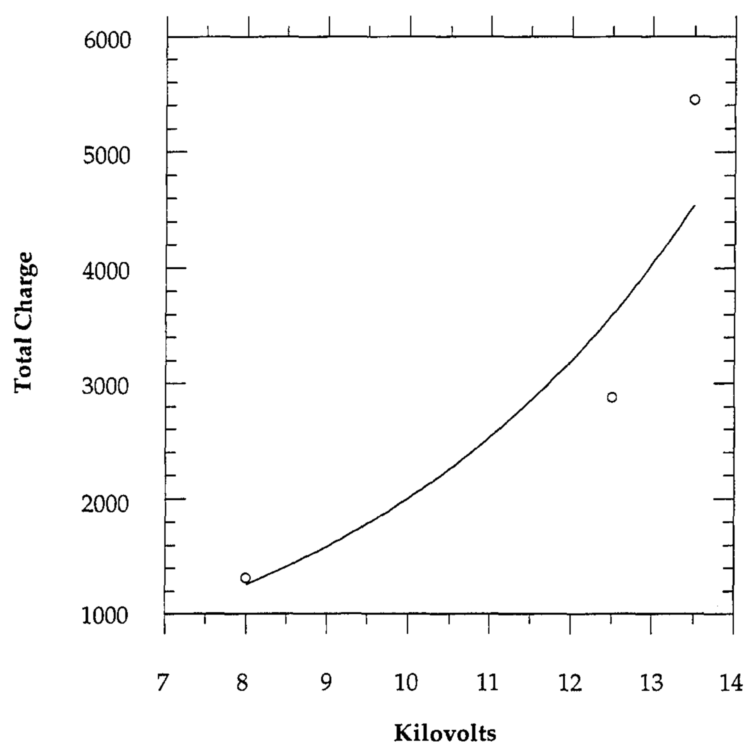

Figure 7. Integrated Charge vs. Kilovolts

4.0 CONCLUSIONS

Under certain simulated environmental conditions, partial discharge activity on the high voltage leads is significant. The RF energy radiated from such discharges may couple to other wiring within the harness. It may also affect the quality of the image on the CRT. In future tests, video signals should be included in the harness to gauge actual RF noise problems.

The FEP insulation on the high voltage leads has a dielectric breakdown strength greater than 20 kilovolts dc. While operating voltages will be well under this level, this set of tests points out, not uniquely, that partial discharges can occur at operating voltages far below the dielectric breakdown voltage. This is particularly true at subatmospheric ambient pressures.

With the CIV thresholds well below the tested voltage ratings at all pressures, it is likely that some PD induced degradation will occur in the harness as presently designed. While it is recognized that such PD activity can shorten the harness life, it must also be realized that the highest activity was measured at a pressure (34 torr), unlikely to be seen in normal operation. If this harness is anticipated to be a critical component in determining the MTBF of the overall system or to be an RFI source to signal leads, design changes should be considered. For example, a grounded coaxial shield on all high voltage leads in the harness may solve such problems, though at some higher cost. As a minimum, it is recommended that future testing of this harness be conducted to determine (1) the effects of PD activity on the CRT image and (2) voltage and endurance/aging of the high voltage leads in the harness.

5.0 REFERENCES

[1] P.T. Bapu, J.M. Aulds, S.P. Fuchs, D. McCormick, "Quick-Disconnect Harness for Helmet-Mounted Displays," Proceedings SPIE Helmet Mounted Displays III, Orlando FL., April 1992.